An Examination of Benthic Macroalgae Communities as Indicators of Nutrients in Middle Atlantic Coastal Estuaries - Maryland Component
Final Report 1998 - 1999

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Resource Assessment Service
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Annapolis, MD 21401

May 2001

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ACKNOWLEDGEMENTS

This project, entitled *An Examination of Benthic Macroalgae Communities as Indicators of Nutrients in Middle Atlantic Coastal Estuaries - Maryland Component Final Report 1998 - 1999,* was funded by the U.S. Environmental Protection Agency via University of Delaware under Contract NO. CR826092-01-1 to Maryland Department of Natural Resources.

The authors gratefully acknowledge the U.S. EPA and the University of Delaware for financial support of this project. We would also like to thank Chris Millard, Dan Ostrowski, William Rodney and Jeff Ramsey for assistance in data collection. Thanks also to Patricia Matthews for assisting in all of the administrative details associated with this project, and to Cathy Wazniak for reviewing and editing this report.

INTRODUCTION

More than one-half the nation's population now lives and works within 50 miles of the coastline, but coastal areas account for only 11 percent of the nation's land area. In recent years, 40 percent of new commercial development and 46 percent of new residential development happened near the coast (NOAA). As the population grows and there are more people living near our coasts, potential threats to the health and productivity of coastal waters increases. Nitrogen and phosphorus loads from wastewater, fertilizer and atmospheric deposition increases. Lawn care, transportation, water treatment and energy generation practices all have the potential to deliver toxic compounds to local waterways, either directly through surface run off or indirectly through groundwater contamination and atmospheric deposition. These threats and their attendant effects on the natural resources need to be evaluated.

The ocean coastal area of Maryland is a microcosm of these nationwide trends. This area represents a small watershed in Worcester County, Maryland. The coastal bays watershed covers approximately 200 square miles with a narrow, yet well develop beach front. Recreational and tourism opportunities have attracted many year round and transient residents resulting in large population increases over the last few decades. Maryland Department of Planning census data show nearly a twofold increase in population in Worcester county since 1970, with population at in 1970 at 24,442 increasing to 43,950 in 2000. (These numbers represent the permanent residents, however on any given weekend over the summer, population can reach well over 100,000 individuals). Much of this growth has occurred and will continue in the Maryland Coastal Bays watershed. "Census statistics for 1990 show approximately 62 percent of the population living in the coastal bays watershed and by 2020 that percentage is expected to rise to 73 percent. To accommodate this population growth, many acres of uplands, wetlands and forest, and productive farmland in the county have been converted both to residential and commercial use." Maryland Coastal Bays Program, 1997. This scenario of growth and land development have generated concern for the coastal resources that are both economically and ecologically important for the livelihood of the residents and economy of Worcester County.

In 1997, the Maryland Coastal Bays Program identified eutrophication as the "single greatest environmental problem in the coastal bays" (MCPB, 1997). They also cited a need to better understand the "extent of eutrophication in the bays *to* aid in targeting and tracking restoration efforts" (MCBP, 1997). In 1998, the Maryland Department of Natural Resources entered into a joint assessment project with the University of Delaware. The purpose of the study was to evaluate the relationships among nutrient concentrations, phytoplankton and macroalgae in the coastal embayments along the Delmarva Peninsula. The primary objective of this study is to test the null hypothesis: Nutrient enrichment does not influence the distribution of aquatic plants or promote shifts in the primary producer community along a nutrient gradient. The alternate hypothesis states nutrient enrichment does influence these communities along the gradient. For this study, the specific measurement parameters were macroalgae volume, chlorophyll *a* concentration, and nutrients.

A secondary objective of the study was to determine if macroalgae biomass is an adequate indicator of nutrient levels. Macroalgae have become the focus of indicator development efforts, due to their life histories (Shubert 1984). Because macroalgae aren't vascular plants, and do not use a root system to remove nutrients from the sediments, they must get their nutrients from the surrounding environment. As a result, macroalgal tissues often closely reflect water column contents, including nutrients (Shubert 1984, Lapointe et al. 1992; Peckol et al. 1994; Horrocks et al. 1995). While there are many factors affecting the growth of macroalgae, including temperature (Broderick and Dawes 1998), light availability (Mazzella and Alberte 1986; Dawes 1995), grazing (Hauxwell et al. 1998; Valiela et al. 1997a), and desiccation (Broderick and Dawes 1998), a large increase in macroalgal biomass has most often been associated with eutrophication (Shubert 1984,;Lapoointe et al. 1992; Valiela et al. 1992; Fong et al. 1993; Peckol et al. 1994; Taylor et al. 1995; Timmons and Price 1996; Valiela et al. 1997a; Hauxwell et al. 1998; Kinney and Roman 1998). Valiela et al. (1992) found that a rise in nutrients increased algal biomass 3-4 levels of magnitude, shading out eelgrass, creating more anoxic events, and changing the benthic faunal communities. Hauxwell et al. (1998) also found that as nitrogen loading increased, macroalgal biomass increased by three times. In 1993, Fong et al. ran a series of microcosm experiments and found that nitrogen levels directly controlled the macroalgal biomass, and which in turn controlled levels of phytoplankton. In this study we sampled the coastal bays of Maryland and Virginia from June through December 1999 in an attempt to correlate levels of nitrogen and phosphorous with macroalgae biomass.

Additionally, this study yielded much needed information on the composition of macroalgae in the Maryland coastal bays as well as providing cursory distribution maps. This report summarizes the results of the Maryland portion of this joint study.

Study Area

This part of the study focused on the Maryland coastal bays, located within Worcester County, MD. These bays are formed by two barrier islands (Fenwick and Assateague) and consist of the Assawoman, Sinepuxent, and Chincoteague bays, the Isle of Wight, Newport and St Martin's River, and various smaller tidal creeks. The surrounding land is generally composed of sandy, poorly drained soils with very low gradients. *Spartina* dominated wetland types border the majority of the coastal bays. The water depth in the bays is predominantly shallow, rarely deeper than two meters. The coastal bays watershed is relatively small, covering approximately 200 square miles. The Maryland portion of Fenwick Island is dominated by the well developed resort town of Ocean City, which in summer months can influence the areas population size dramatically, with some estimates putting the areas population well over 100,000 during summer weekends. In contrast, Assateague Island is an environmentally protected area (through both state and federal parks) with little development. The west coast of the coastal bays is sparsely developed, but supports a moderate amount of agricultural and farming operations.

Previous investigations

In 1993, the Environmental Monitoring Assessment Program (EMAP) conducted an assessment of the ecological condition of the Delaware and Maryland coastal (EPA, 1996). This project utilized a probability-based sampling design that incorporated strata representing bottom sediment types and chlorophyll *a* concentrations. This allowed assessment of the coastal bays as a whole. Each of the four major subsystems within the coastal bays (Rehoboth Bay and Indian River Bay, Delaware, and Assawoman Bay Chincoteague Bay, Maryland) and four areas of special interest (Upper Indian River, Delaware, St. Martin River and Trappe Creek, Maryland, and dead end canals in both states) were sampled for biological and chemical measures. Timmons and Price (1996) conducted a conventional study of the abundance and species composition of macroalgae for Rehoboth and Indian River Bays during 1992 and 1993, and Orris and Taylor surveyed benthic macroalgae of Rehoboth Bay in 1973. Linder et al.(1996) reported the ecological integrity of the Maryland coastal bays. Orth et al.(1996) reported submerged aquatic vegetation distribution in Chincoteague Bay. Wells et al. (1994) mapped sediment types within the coastal embayments and reported an east to west gradient of dominant mud in the west that transitions to sand toward the eastern side of the bays.

Nutrient conditions

Excess nutrient loads can cause eutrophic conditions in aquatic ecosystems. Eutrophication process can lead to depletion or extinction of dissolved oxygen, leading to decline or depletion of valuable biological resources. Previous studies by Bohlen and Boynton (1998) and EMAP (1996) found a north to south nutrient gradient in the coastal embayments, with higher nutrient concentrations in the north region of Maryland's coastal bays. Price (1993) reported that in the Indian River Bay, phytoplankton levels were most prolific (as measured by chlorophyll *a* concentrations) in the portions of the estuary closest to nutrient sources (e.g., upper and middle Indian River Bay). The most turbid water in the coastal embayments is witnessed in the summer season and probably results from a combination of biological effects (plankton blooms) and physical effects (boat traffic) (Ullman et al.1993). Secchi depths in upper Indian River average approximately 0.5 meters year-round, but may be as low as 0.10 meters in the summer season during extremely high chlorophyll concentrations (Ullman et al.1993). These nutrient fluctuations likely play a significant role in defining limitations on the coastal embayments biological structure and integrity.

Submerged Aquatic Vegetation (SAV) and Macroalgae

Submerged aquatic vegetation (SAV) is an important resource in the Delmarva coastal bays. SAV is both commercially and ecologically important, providing critical habitat for various fish, crabs, and shellfish. The presence or absence of SAV can also be a useful indicator of water quality conditions and nutrient levels (Dennison et al.1993).

Sea grass beds in the Delmarva coastal bays suffered a serious decline in the 1920's and 1930's, in part due to disease (Orth et al.1998). During the 1970's SAV beds were also effected by an extremely large input of sediment and nutrient levels due to Tropical Storm Agnes (Orth et al.1998). Orth et al. (1997) reported that circular clam dredging within the Chincoteague Bay, Virginia was negatively effecting and degrading existing SAV beds. Orth and Moore (1998) also found hydraulic clam dredging in Maryland negatively effecting beds in the Chincoteague and Sinepuxent Bays. In recent years the coastal bay SAV beds have increased in size. In 1986, there was a reported 2,128.83 hectares of SAV. In 1996 there was an increase in bed size to 4,558.56 (Orth et al. 1996). This overall increase in SAV has been documented in most areas of the Chesapeake Bay region.

Timmons and Price (1996) and Orris and Taylor (1973) documented multiple species of benthic macroaglae in the Delaware coastal bays. Timmons and Price (1996) found *Agardhiella tenera* dominant in Rehoboth Bay, and *Ulva lactuca* dominant in Indian River. These species dominance are similar to results reported by Orris and Taylor (1974). Timmons and Price reported instances of SAV being smothered by benthic macroalgae communities, and suggest that nutrient level fluctuations influence macroalgae abundance. Macroalgae habitats were found to be utilized by some juvenile fish species and crabs (Timmons and Price, 1996).

METHODS

Sampling was conducted over a two-year period, 1998 and 1999. A combination of fixed and random stations was sampled each year. Evaluation of 1998 data pointed to the need to change sampling approaches in 1999 in order to better sample the algal community, and gain better sampling coverage within each individual embayment. Each site was sampled for nutrients, physicochemical parameters, and macroalgae abundance.

Macroalgae Sampling

In 1998, macroalgae sampling was conducted from April through October. A stratified random sampling design was applied to account for seven strata within the coastal embayments. These strata were based on sediment type (sand, mud and mixed sand/mud) and frequency of high chlorophyll *a* concentration (high, moderate, low) (Wells et al. 1998). Twenty one stations, one fixed station and two random stations per strata, were sampled on a monthly basis. Stations were located using a Magellan differential GPS unit. Stations were deemed sampleable if water depth was greater than one meter. If water depth was less than one meter, an alternate station within the same strata was chosen.

Macroalgae were sampled using a benthic sled dredge in April. This gear type was deemed impractical for the task. The steel construction of the sled dredge caused the apparatus to quickly sink into the bottom sediments. In place of the sled dredge, a 3.1 m otter trawl (6.4 mm stretch mess, 50.8 x 25.4 mm doors) was used from May to October. Tide state and water depth was determined and recorded at each station. When conditions were adequate for sampling, the boat traveled down current, at low but adequate speed to assist the biologist deploying the trawl. Once deployed, the boat operator increased engine RPM to 1200 (approximately 2 knots), recorded start latitude and longitude position and start time. After a tow distance of 91 meters, the boat operator placed the engine in reverse to stop the progress of the vessel, and recorded stop latitude and longitude position. At this time, the trawl was retrieved and contents of the cod end were placed on a culling table and sorted. Collected specimens were placed in various sized whirl packs, and labeled with station number, date, collectors' initials, and tow number. Samples were placed on ice and identified in the laboratory within one week of collection. The sampling procedure was repeated at each station, heading up current, parallel to the path of the first sampling effort. Macroalgae and submerged aquatic vegetation were identified to genus level (species level when possible) using a dissection microscope and various taxonomic keys. Total volume of each genus in a sample was measured using volumetric displacement methods. Volumes over 100 ml were measured to the nearest ten ml. Volumes less than 100 ml were measured to the nearest one ml.

Evaluation of the data after the 1998 sampling period showed that the stratification based on sediment type was not necessary. Analysis of variance showed that the volume of macroaglae among the strata were not significantly different ($p = 0.3804$). The decision was made prior to the 1999 sampling season to stratify the sampling among the embayments to increase the database of information for each embayment.

In 1999, macroalage samples were collected using an aluminum sled dredge. The principle investigator to insure easy comparisons of data between states instituted this change. Like the trawl, the dredge was deployed and towed over a distance of 100 meters. All other procedures were followed as previously described.

Water quality data were collected prior to sampling macroalgae. Temperature, dissolved oxygen (DO), pH, specific conductance, and salinity were recorded at 0.5 meters from the bottom and 0.5 meters from the surface using a Hydrolab^{TM} Surveyor III. A Secchi depth was recorded at each sampling station.

Water samples were collected at 0.5 meters from the surface utilizing a standard submersible pump. Water was allowed to run through the pump for approximately 30 seconds to adequately rinse the apparatus with sample water. After this time, a plastic container was rinsed three times with the sample water, then filled with sample water. Whole water samples were immediately placed on ice and filtered and processed directly upon returning to land. Water samples were sent to the University of Maryland, Chesapeake Bay Laboratory (UMD, CBL) and analyzed for orthophosphate, nitrate, nitrite, ammonia, silica, total suspended solids, total dissolved nitrogen, total dissolved phosphorus, particulate carbon and nitrogen, particulate phosphorus, dissolved organic carbon, and chlorophyll *a*. Samples collected for dissolved constituents, total suspended solids, and chlorophyll *a* were filtered in the field using negative filtration techniques. Water samples collected for laboratory analysis were prepared and handled according to standards developed for the Chesapeake Bay Program Water Quality Monitoring component (Haire et al. 1998).

RESULTS

A total of 113 sites were sampled from May to October of 1998 (Table 1). Due to inconsistent sampling methodology, data from April was not included in the analyses. Twenty-four stations (21% of the stations sampled) showed no vegetation in either haul. In 1999, sampling was conducted from June through December. A total of 133 stations were sampled (Table 2). Because weather and equipment problems hindered sampling in June and July, the season was extended through December. Of the 133 stations sampled, 43 stations (32% of the stations sampled) had no vegetation in either haul. Figure 1 shows the stations sampled for both years combined. Table 3 shows the break down of sampling effort by embayment for each year.

	May	June	July	August	September	October	**Total**
# of Sites	21	21	21	21	21	21	**126**
# **of Sites Sampled**	16	21	15	21	19	21	**113**

Table 1. Number of sites sampled per month in 1998.

	June	July	August	Septem-ber	Octo-ber	Novem-ber	Decem-ber	**Total**
# of Sites	21	21	21	21	21	21	0	**126**
# **of Sites Sampled**	14	14	21	21	21	21	21	**133**

Table 2. Number of sites sampled per month in 1999.

	Assawoman	St. Martin	Isle of Wight	Sinepuxent	Newpor t	Chincoteague
1998	5	15	15	15	15	51
1999	12	19	20	18	20	46

Table 3. Number of stations sampled by embayment for 1998 and 1999.

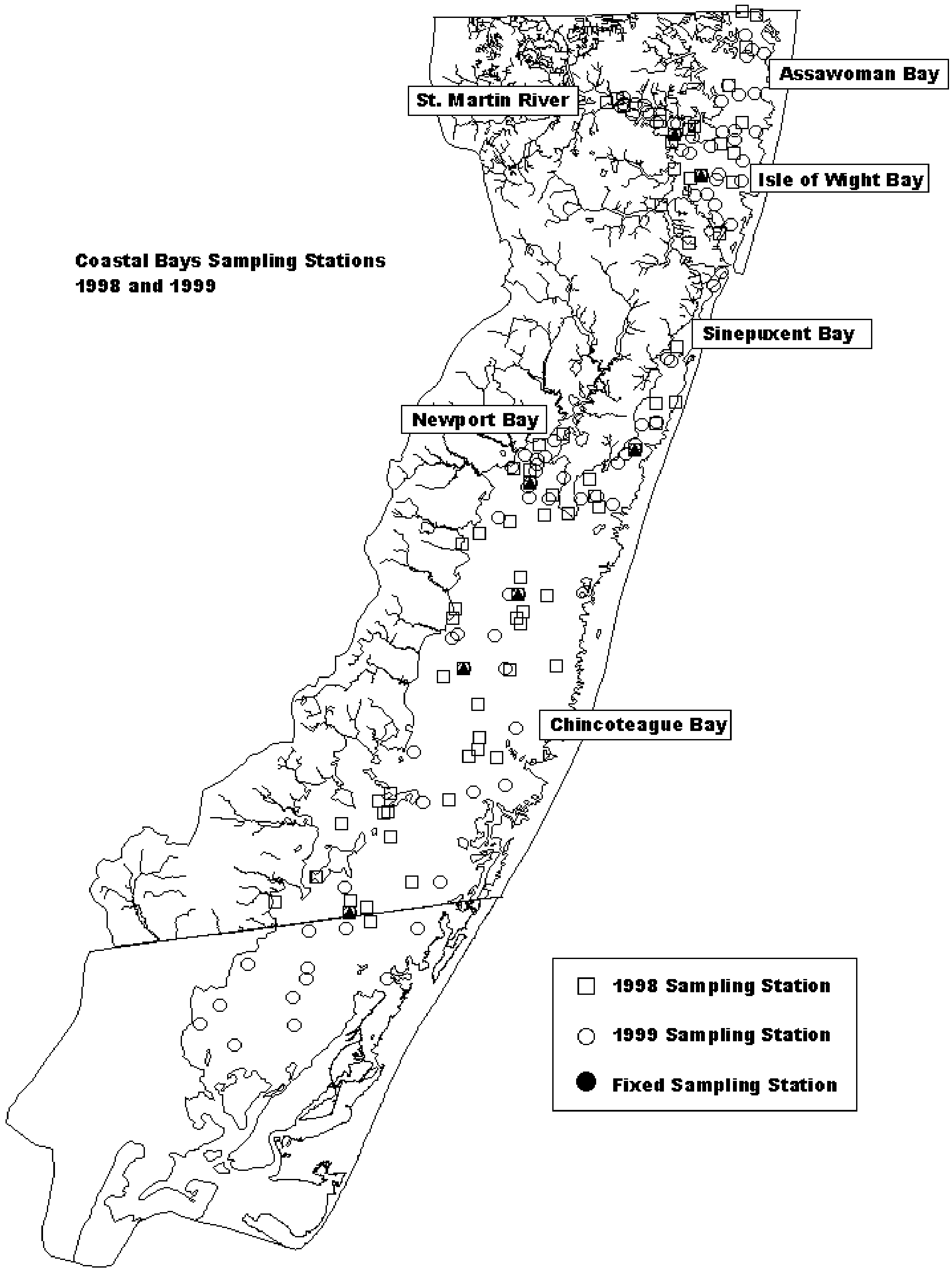

Figure 1. Sampling stations, 1998-1999.

Green Algae (Chlorophyta)	Red Algae (Rhodophyta)	Brown Algae (Phaeophyta)
Bryopsis, Chaetomorpha, Cladophora, Codium, Enteromorpha, Spongomorpha, Ulothrix, Ulva	*Agardhiella, Ahnfeltia, Ceramium, Champia, Chondria Cystoclonium, Gracilaria, Hypnea, Griffithsia, Polysiphonia, Ptilota, Spyridia*	*Desmarestia, Ectoarpus, Eudesme, Sphaerotrichia, Stilophora*

Table 4. Macroalgae genera observed in Maryland Coastal Bays, 1998 and 1999.

<u>*Macroalgae*</u>

Twenty-five genera were documented in the Coastal Bays of Maryland in 1998 and 1999 (Table 4). In 1998, a total of seventeen genera were observed with twenty-two being observed in 1999. Both years show a dominance of red algae, with a few more genera of brown algae appearing in 1999. As seen in Table 5, the most abundant and frequently observed genera were *Gracilaria spp.* and *Aghardiella spp.* In 1999, *Aghardiella spp.* and *Chaetomorpha spp.* ranked highest for total abundance, however, *Gracilaria* and *Polyshiphonia spp.* were the most frequently observed genera. Overall, *Agardhiella spp.* and *Graciliaria spp.* were the most abundant genera represented, and *Gracilaria spp.* and *Ulva spp.* were the most frequently observed genera. Six genera represent 90% of the total volume. They include *Agardhiella spp., Gracilaria spp., Enteromorpha spp., Champia. spp,* and *Polysiphonia spp*. Seven genera, *Gracilaria spp., Ulva spp., Agardhiella spp., Polysiphonia spp., Enteromorpha spp., Champia spp.* and *Ceramium spp.*were found at 20% or more of the stations sampled. Figures 2 and 3 show the distribution of each genus. Most of these genera appear to have fairly widespread distribution among both years sampled. However, *Ulva spp*. appears to be clustered in the upper Coastal Bays in the vicinity of St. Martin River and Assawoman Bay and also in the Southern portion of Chincoteague Bay. Figure 4, a box and whisker diagram shows the number of genera by embayment for 1998 and 1999. Chincoteague bay showed the greatest genera richness in 1998, where Sinepuxent had the highest richness in 1999. Table 6 shows the total number of genera with means and ranges by embayment. The increase in richness in Sinepuxent Bay in 1999 could be due to the difference in sampling effort between the years. In 1998, stations were selected based on sediment and chlorophyll *a* strata. In 1999, strata were based on embayments alone, thus in 1999 there was a more balanced sampling effort among embayments (Table 3). When adjustments to genera totals are made for effort (dividing total genera by total effort), Assawoman Bay had the largest richness per effort in 1998 and Sinepuxent in 1999, and Chincoteague Bay appeared lowest in 1998 and second lowest in 1999 (Figure 5). Figure 6 shows the mean number of genera by embayment for each month sampled for 1998 and 1999 combined. This figure shows the diversity increasing in the fall. Table 7 shows the total volume by embayment and the volume per station by embayment. Note that Isle of Wight Bay in both years showed the highest volume and largest volume per station, even though the diversity was lower here than the more southern embyaments. When looking at richness by station (Figure 7), southern Chincoteague Bay appears to have the highest diversity. It is interesting to note that the stations along the Maryland/Virginia boarder display some of the highest richness numbers observed. Table 8 shows the number of genera that accounted for 90% of the volume of macroalgae examined. In terms of genera comprising 90% of the volume, Chincoteague and Isle of Wight Bays show good diversity in 1998 and Sinepuxent and Chicoteague in 1999. When cluster analysis was conducted on the data to determine how the genera might group according to total volume observed, *Aghardiella spp.* and *Chaetomorpha spp.* fell into a distinctly separate cluster from all other genera (Figure 8).

Abundance			Frequency		
1998	**1999**	**Combined**	**1998**	**1999**	**Combined**
Gracilaria	*Agardhiella*	*Agardhiella*	*Gracilaria*	*Gracilaria*	*Gracilaria*
Enteromorpha	*Chaetomorpha*	*Gracilaria*	*Enteromorpha*	*Polyshiphonia*	*Ulva*
Ectocarpus	*Champia*	*Chaetomorpha*	*Agardhiella*	*Champia*	*Agardhiella*
Agardhiella	*Graciliaria*	*Enteromorpha*	*Ulva*	*Ulva*	*Polysiphonia*
Chaetomorpha	*Polysiphonia*	*Champia*	*Ceramium*	*Agardhiella*	*Enteromorpha*
Ulva	*Ahnefeltia*	*Polysiphonia*	*Polysiphonia*	*Enteromorpha*	*Champia*
Polysiphonia	*Enteromorpha*	*Ectocarpus*	*Spyridia*	*Ceramium*	*Ceramium*
Ceramium	*Ulva*	*Ulva*	*Chaetomorpha*	*Stilophora*	*Spyridia*
Spyridia	*Desmarestia*	*Ahnefeltia*	*Chondria*	*Sphaerotrichia*	*Chaetomorpha*
Codium	*Sphaerotrichia*	*Ceramium*	*Champia*	*Desmarestia*	*Chondria*
Champia	*Stilophora*	*Spyridia*	*Ectocarpus*	*Chaetomorpha*	*Stilophora*
Hypnea	*Spongomorpha*	*Codium*	*Cladophora*	*Spyridia*	*Desmerestia*
Chondria	*Ceramium*	*Desmarestia*	*Hypnea*	*Hypnea*	*Sphaerotrichia*
Cladophora	*Chondria*	*Sphaerotrichia*	*Codium*	*Cystoclonium*	*Hypnea*
Stilophora	*Spyridia*	*Stilophora*	*Ulothrix*	*Bryopsis*	*Ectocarpus*
Ulothrix	*Cystoclonium*	*Chondria*	*Stilophora*	*Ahnfeltia*	*Cladophora*
Eudesme	*Hypnea*	*Hypnea*	*Eudesme*	*Griffithsia*	*Cystoclonium*
	Bryopsis	*Spongomorpha*		*Chondria*	*Bryopsis*
	Griffithsia	*Cladophora*		*Spongomorpha*	*Ahnfeltia*
	Cladophora	*Cystoclonium*		*Codium*	*Codium*
	Ptilota	*Bryopsis*		*Ptilota*	*Griffithsia*
		Griffithsia			*Spongomorpha*
		Ptilota			*Ptilota*
		Ulothrix			*Ulothrix*
		Eudesme			*Eudesme*

Table 5. Macroalgae genera for 1998, 1999 and the two years combined, in order of abundance and frequency from greatest to least.

Location	Total Species		Mean		Range	
	1998	1999	1998	1999	1998	1999
Assawoman Bay	6	9	1.4	1.25	0 - 6	0 - 6
Chincoteague	18	21	3.5	3.1	0 - 12	0 - 11
Isle of Wight Bay	7	15	2.2	3.0	0 - 6	0 - 9
Newport Bay	12	11	1.5	1.2	0 - 10	0 - 7
Sinepuxent Bay	11	20	2.8	5.3	0 - 8	0 - 11
St. Martin River	9	8	2.1	0 8	0 - 6	0 - 6

Table 6. Total number of genera, mean number of genera and range of number of genera by embayment.

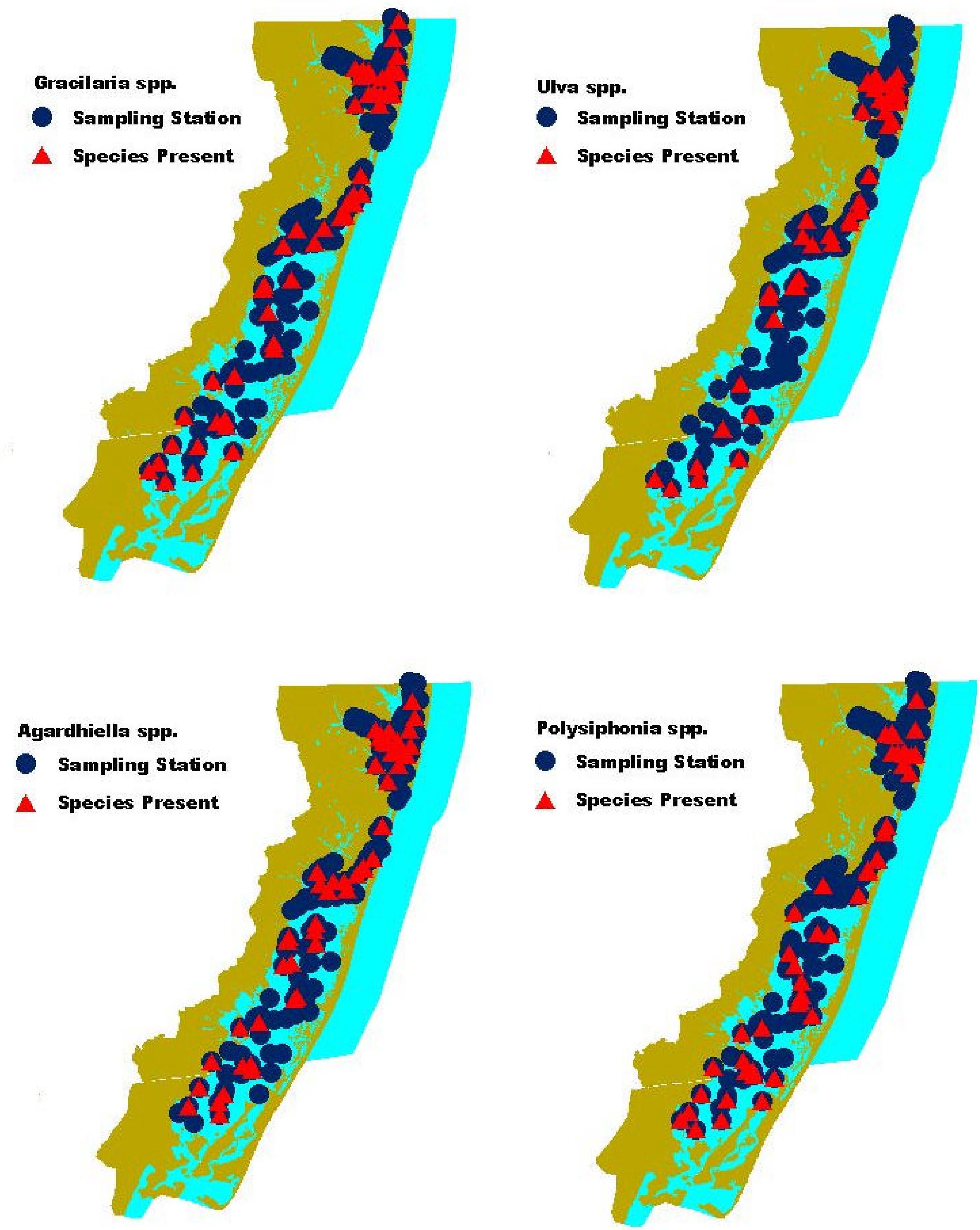

Figure 2. *Gracilaria, Ulva, Agardhiella* and *Polysiphonia* distribution, 1998-1999.

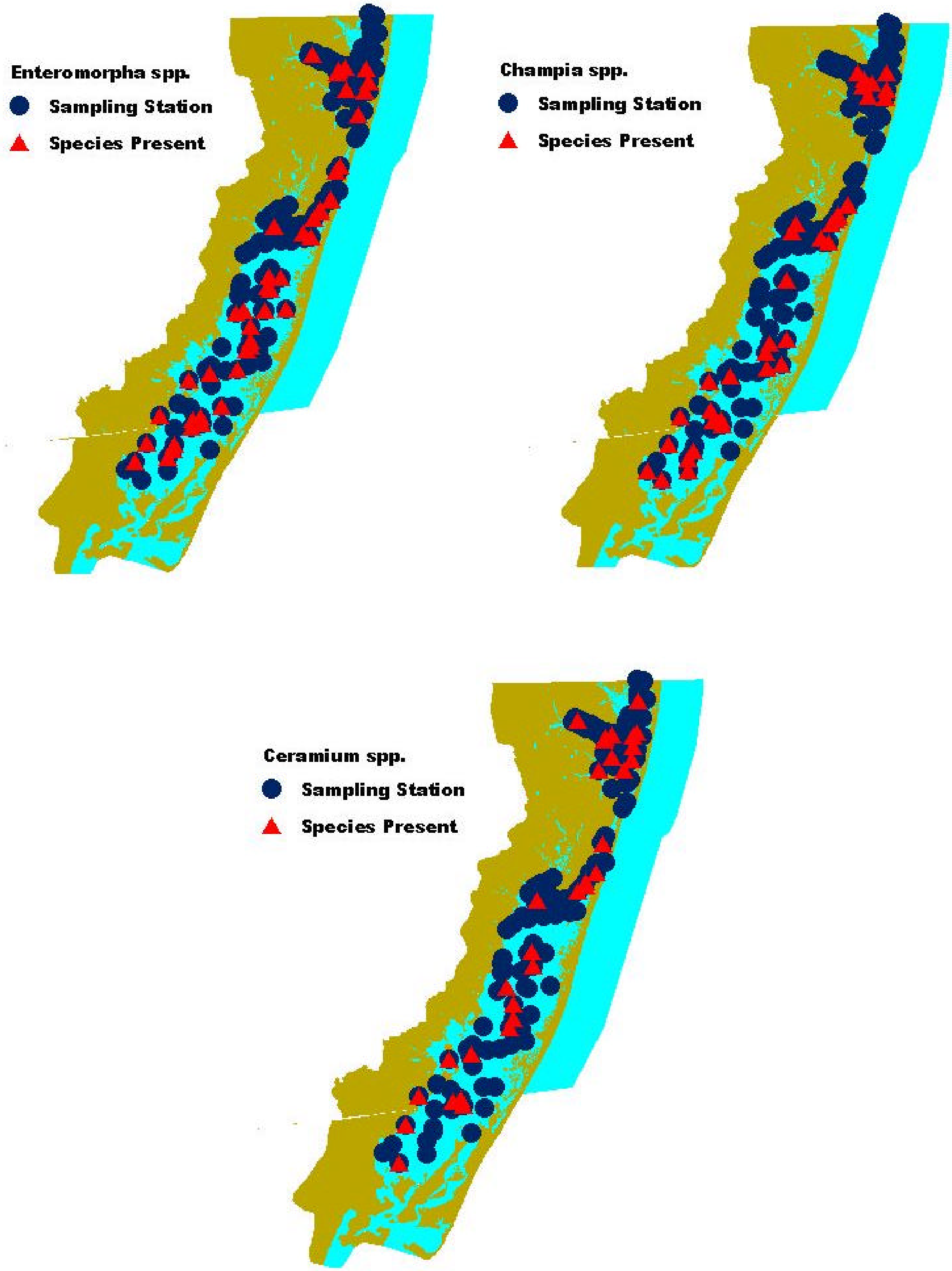

Figure 3. *Enteromorpha, Champia* and *Codium* distribution, 1998-1999.

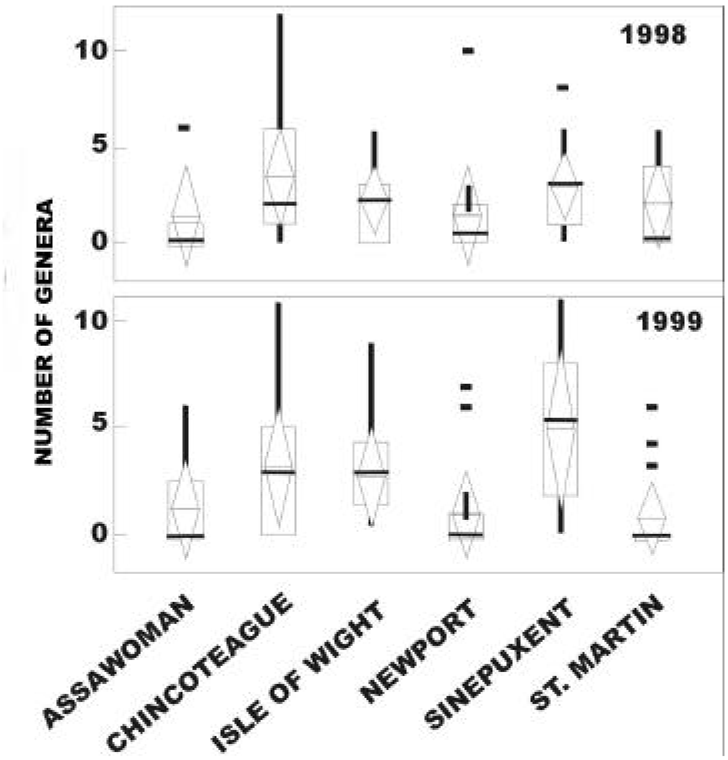

Figure 4. Genera richness by embayment, 1998 and 1999.

Embayment	Total Volume 1998	Volume/Station 1998	Total Volume 1999	Volume/Station 1999
Assawoman	874	786.6	86.5	7.2
St. Martin	716.5	47.8	591	31.1
Isle of Wight	18852	1256.8	57089.5	2854.5
Sinepuxent	1046.5	69.8	6182	343.4
Newport	580	38.7	715	35.8
Chincoteague	16269.5	319.1	23638.5	513.9

Table 7. Total macroalgae volume and volume per station for each embayment by year.

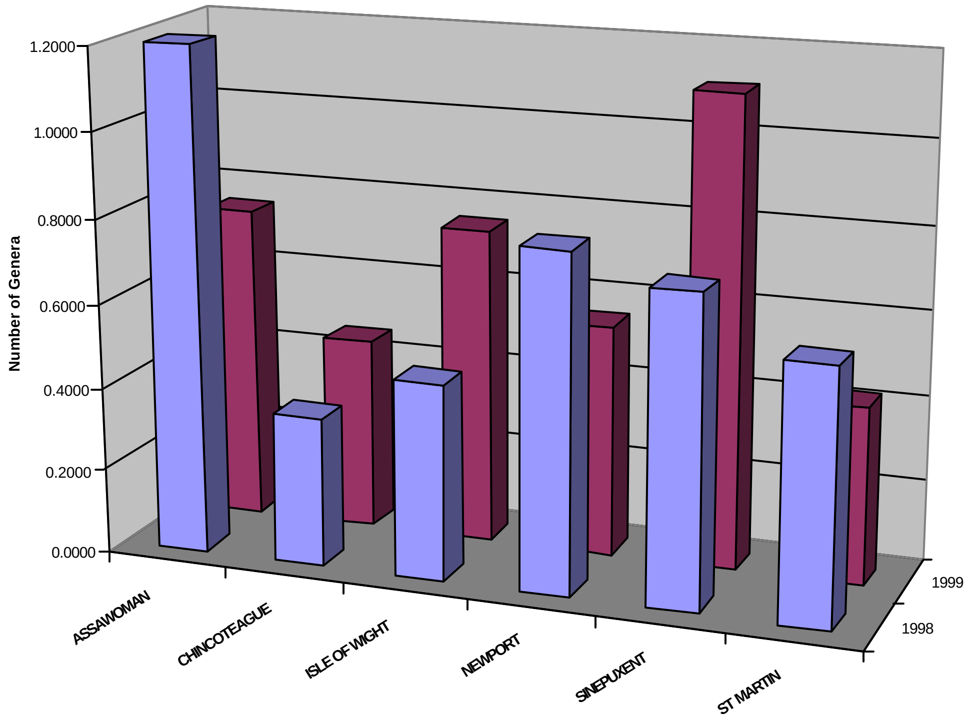

Figure 5. Number of genera by embayment adjusted for effort by year

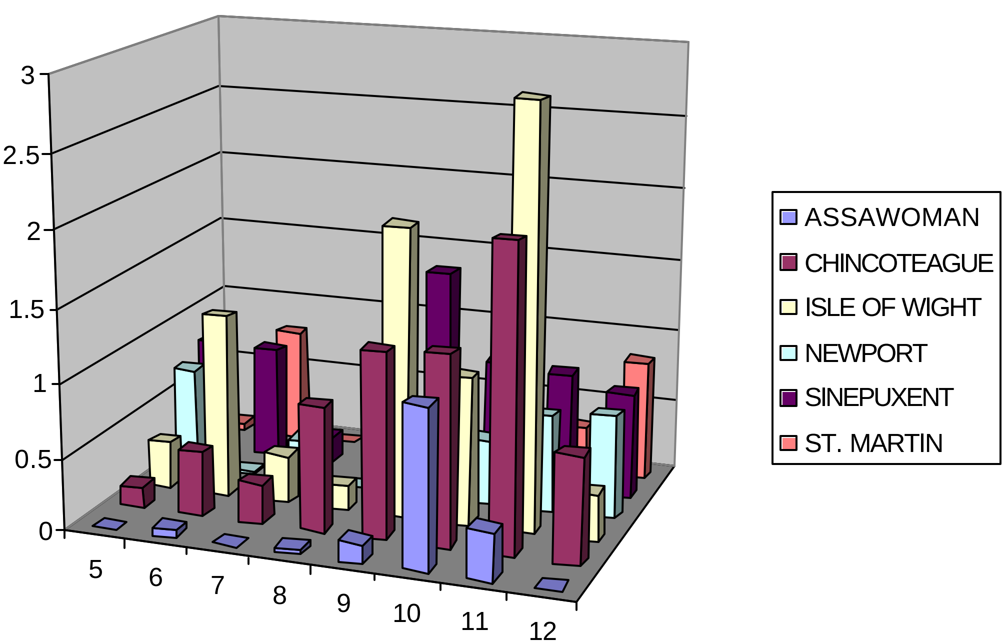

Figure 6. Mean number of genera by month for each embayment, 1998 and 1999 combined.

Embayment	Number Genera comprising 90% of the Volume 1998	Genera that comprise 90% volume (great to least) 1998	Number Genera comprising 90% of the Volume 1999	Genera that comprise 90% volume (great to least) 1999
Assawoman	3	*Ulva* *Gracilaria* *Aghardhiella*	4	*Polysiphonia* *Agardhiella* *Gracilaria* *Cystoclonium*
St. Martin	3	*Aghardiella* *Ulva* *Gracilaria*	4	*Gracilaria* *Aghardhiella* *Desmarestia* *Polysiphonia*
Isle of Wight	2	*Gracilaria* *Agardhiella*	2	*Agardhiella* *Champia*
Sinepuxent	5	*Ulva* *Gracilaria* *Hypnea* *Champia* *Agardhiella*	6	*Champia* *Gracilaria* *Agardhiella* *Stilophora* *Enteromorpha* *Chondria*
Newport	7	*Agardhiella* *Ulva* *Polysiphonia* *Hypnea* *Ceramium* *Champia* *Gracilaria*	3	*Champia* *Gracilaria* *Agardhiella*
Chincoteague	7	*Enteromorpha* *Ectocarpus* *Chaetomorpha* *Polysiphonia* *Codium* *Spyridia* *Ceramium*	5	*Chaetomorpha* *Polysiphonia* *Gracilaria* *Enteromorpha* *Champia*

Table 8. Genera that represent 90% of the total volume of each embayment by year.

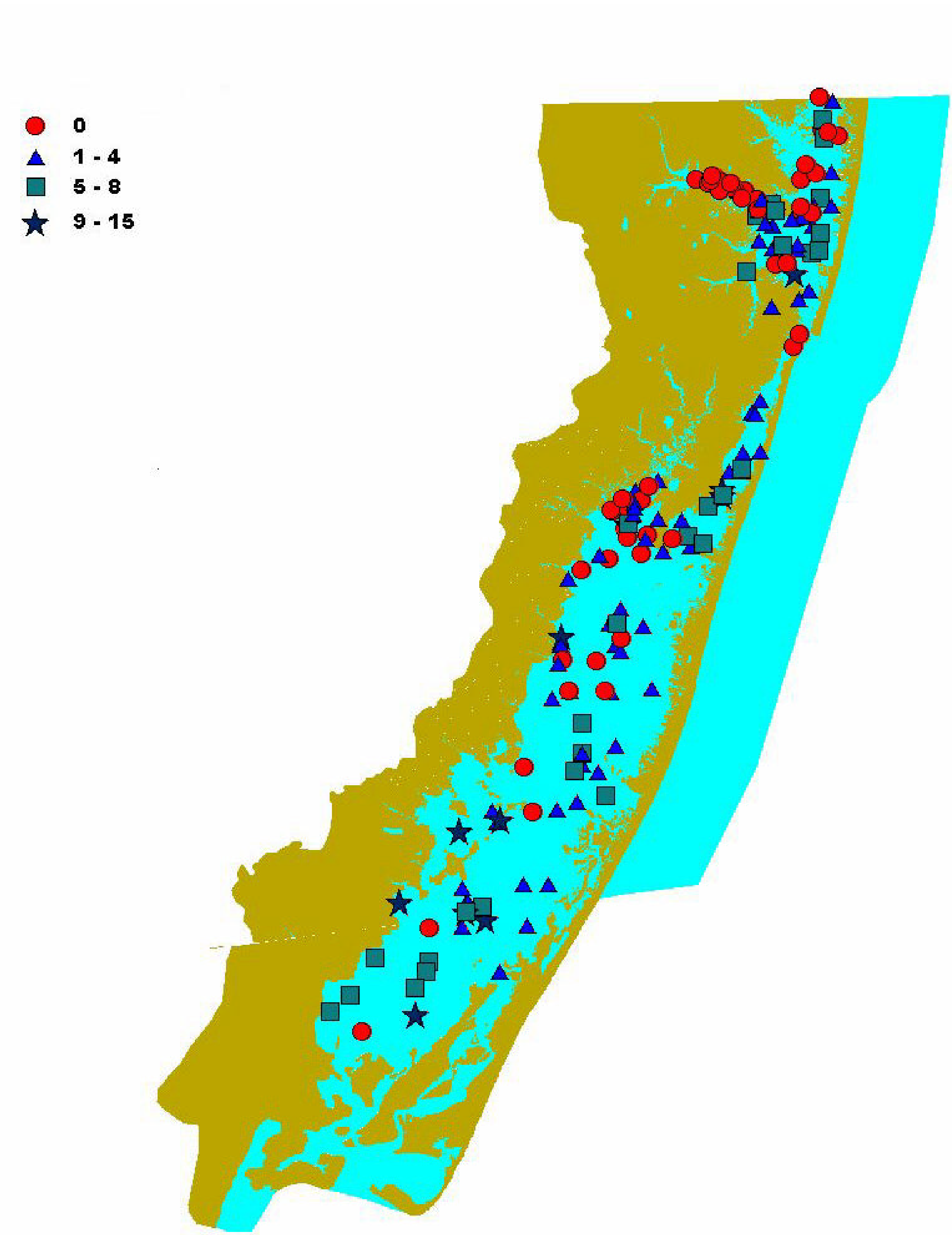

Figure 7. Number of genera per station 1998 and 1999.

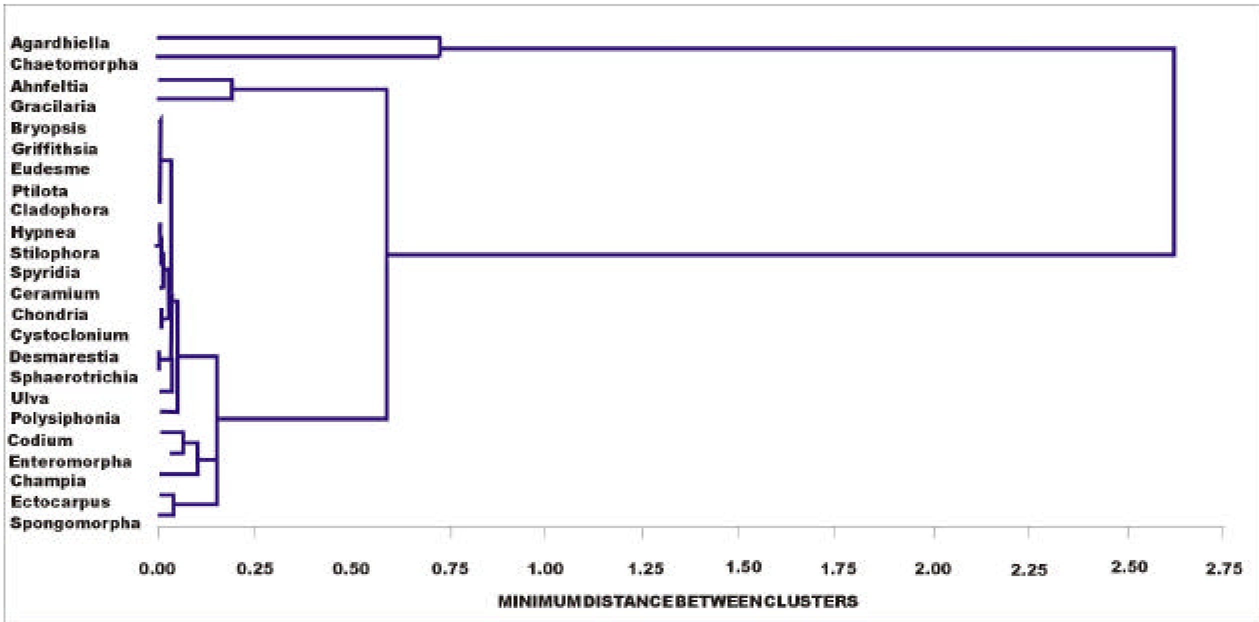

Figure 8. Clustering of genera by total volume.

“Nuisance Macroalgae”

Chaetomorpha spp.

Over the last two years, there has been concern raised over the abundance and distribution of *Chaetomorpha*, especially in relation to SAV beds in the coastal bays. Figures 9 and 10 show SAV and *Chaetomorpha* distribution for 1998 and 1999. *Chaetomorpha* appears to have been more widely distributed in 1998 than in 1999. According to the map, five sampling stations within Maryland fell in SAV beds. Of these five stations, three showed *Chaetomorpha* present, with one of the five stations having the highest volume of *Chaetomorpha* observed that year. Figure 11 shows distribution of *Chaetomorpha* by abundance.

In 1999, the distribution was not as widespread, however six of the eight stations that were in SAV beds showed *Chaetomorpha* present, and again, the highest volume of *Chaetomorpha* observed was found in SAV in Southern Chincoteague Bay. Additional reports of large mats of *Chaetomorpha* have been received and recorded by the Maryland Department of Natural Resources and indicate that the problem is more extensive than shown in our data. This is probably due to the random sample design and the fact that areas less than 1 meter depth were excluded due to sampling constraints (thus, large areas of prime SAV habitat were not sampled).

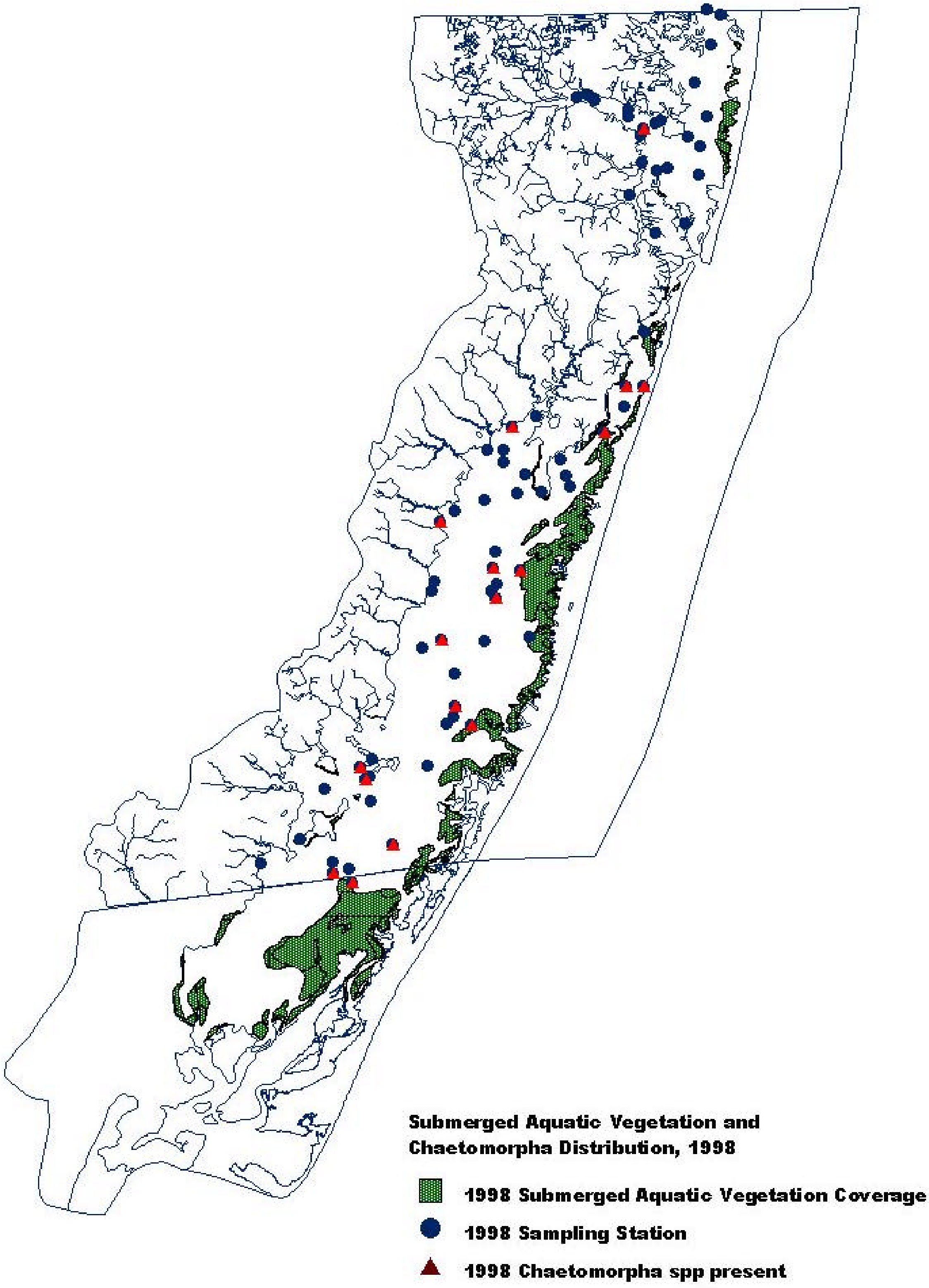

Figure 9. SAV distribution (Orth et al. 1998) and Chaetomorpha presence in 1998.

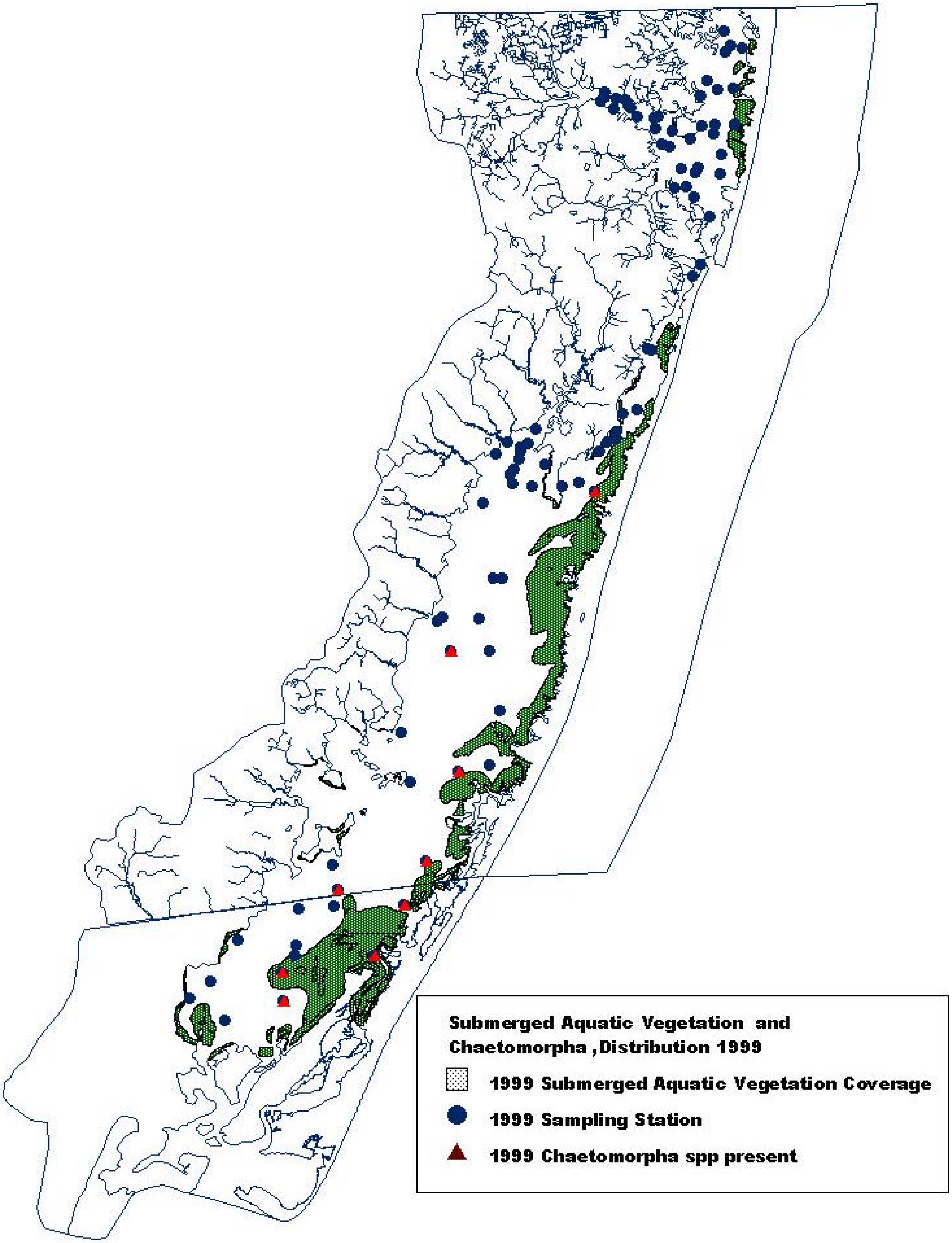

Figure 10. SAV distribution (Orth et al. 1999) and Chaetomorpha presence 1999.

Cladophora spp.

Over the summer of 2000, several citizen reports were received concerning macroalgae blooms that were impeding recreation in the artificial canals around Ocean City and Ocean Pines. When a team was deployed to investigate, they found large dense mats of *Cladophora spp.,* however, the distribution and spatial extent of the blooms was not as dramatic as initially suspected based on the reports (personal observation). In the baywide macroalgae study, small volumes of *Cladophora* were observed at only 7 of the 246 stations or 2.8% of all stations sampled. However, five of these seven stations were in lower Chincoteague Bay local to the Maryland/Virginia boarder (Figure 11).

"Nutrient Responsive Species"

Several species of macroalgae found in the Maryland Coastal Bays have been identified in various studies to be enhanced under nutrient enriched conditions. Harlin and Thorne-Miller (1981) showed that *Enteromorpha spp.* and *Ulva lactuca* showed enhanced growth under increased nitrate loads. Valiela et al (1992) showed that *Cladophora vagabunda* and *Gracilaria tikvahiae* also benefit under nutrient enriched conditions. We assume that based on its growth characteristics that *Chaetomorpha spp.* is also a species that benefits when nutrients are elevated. Another species that we added into this group is *Agardhiella spp*. Though we couldn't find specific references to its nutrient preferences, this species is among the most abundant macroaglae species in Delaware Coastal Bays, where eutrophication problems are well documented (Ullman et al. 1993).

The distribution and abundance for these six genera was examined. Figure 13 shows the genera are well distributed among the embayments. The largest volumes of these six genera appear in Isle of Wight Bay and Southern Chincoteague Bay.

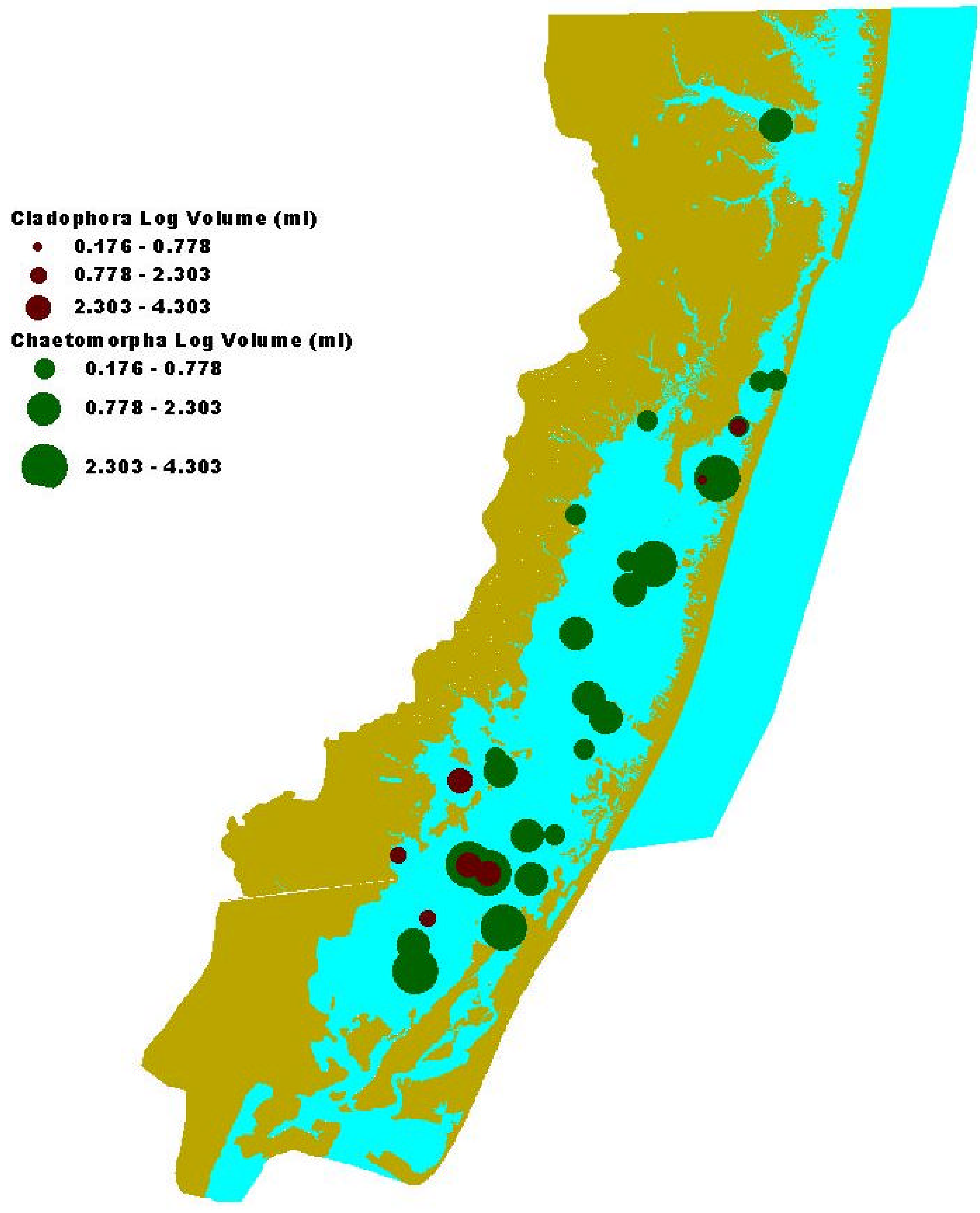

Figure 11. ***Cladophora spp.*** **and** ***Chaetomorpha spp.*** **distribution by total volume for 1998 and 1999.**

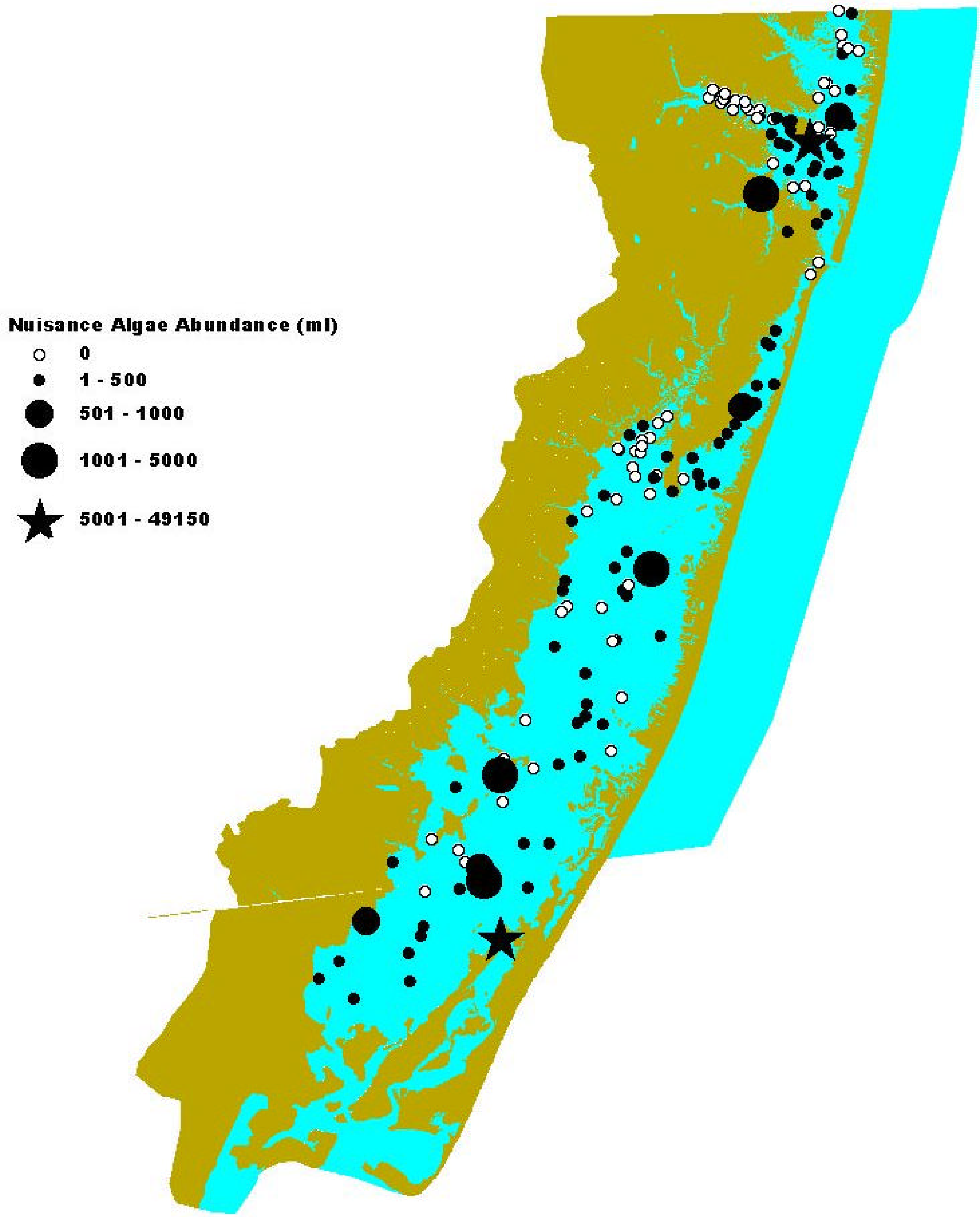

Figure 12. Total abundance of "nutrient responsive" species by station, 1998 and 1999.

Water Quality

Water Quality parameters were evaluated in terms of the entire system and by embayment. Table 9 shows the mean, standard deviation, minimum and maximum values and number of samples for each parameter for all stations combined over both years. Figures 13 and 14 show box and whisker plots of each parameter plotted by embayment. The mean with 90% confidence intervals and the median with the upper 75^{th} and lower 25^{th} percentiles are plotted. The dashed line represents the mean concentration for each parameter for the entire sampling period, all embayments combined. The plots reveal significant variability in all parameters. This is likely due to the range of seasons that are represented in the data. Even considering the large variations, the plots reveal higher mean and median chlorophyll *a* values in St. Martin River and Newport Bay. Water quality parameters from all random stations were compared among embayments using ANOVA. Figure 15 illustrates the results of these analyses. There were no significant differences among the distribution of the means when comparing embayments for silicic acid, dissolved organic nitrogen, dissolved inorganic nitrogen, total phosphorus, dissolved organic phosphorus, total organic phosphorus, particulate phosphorus and total organic carbon. However there were differences among embayments for the other parameters observed. Several parameters showed statistical differences between St. Martin and Chincoteague Bay. Specific results for each parameter are summarized in Figure 15.

Water Quality/Macroalgae Comparisons

A correlation matrix was constructed to explore any possible relationships between water quality parameters and macroalgae abundance. Regressions were run on parameters that were significantly correlated with macroalgae volumes. Figures 16 to 19show the results of these analysis. The relationship between total phosphorus and log of macroalgae volume (figure 16) was positive but weak ($p=0.0064$, $r^2=0.0962$). The relationship between total nitrogen and macroalgae volume (figure 16) showed a bit stronger relationship ($p=0.0001$, $r^2=0.1790$). The strongest relationship was seen between chlorophyll *a* and log of macroalgae volume ($p=0.0001$, $r^2=0.1553$) (figure 18). This strength of the relationship almost doubled when the two outliers at the top right were removed (figure 19). Though the correlation between these two parameters is weak, comparing the distribution of chlorophyll *a* and macroalgae volume suggests that there is a seasonal shift from macroalgae to chlorophyll a dominance as water temperature increases in the summer months. The dominance shifts again to macroalgae in the fall when seasonal temperatures begin to drop (figure 21).

Relationships between these water quality parameters and volume of nuisance algae were also examined (Figures 22 to 24). These relationships also were very weak; the greatest r^2 value was 0.11.

Parameter	N	Min	Max	Mean	Standard Deviation
Chlorophyll *a* (ug/L)	244	0.3	38.9	10.6	9.3
Silicic Acid (mg/L)	244	0.01	4.75	1.44	1.19
Total Nitrogen (mg/L)	236	0.227	2.349	0.835	0.378
Dissolved Organic Nitrogen (mg/L)	251	0.008	1.656	0.455	0.188
Dissolved Inorganic Nitrogen (mg/L)	251	0.002	0.338	0.035	0.042
Total Dissolved Nitrogen (mg/L)	251	0.01	1.68	0.49	0.19
Total Organic Nitrogen (mg/L)	251	0.014	2.325	0.764	0.391
Particulate Nitrogen (mg/L)	251	0.005	1.240	0.309	0.250
Total Phosphorus (mg/L)	244	0.0191	0.1779	0.0667	0.0356
Dissolved Organic Phosphorus (mg/L)	251	0.000	0.048	0.019	0.009
Dissolved Inorganic Phosphorus (mg/L)	244	0.0011	0.0436	0.0127	0.0096
Total Dissolved Phosphorus (mg/L)	251	0.0005	0.0651	0.0310	0.0128
Total Organic Phosphorus (mg/L)	251	0.001	0.163	0.053	0.035
Particulate Phosphorus (mg/L)	251	0.0006	0.1268	0.0340	0.0303
Dissolved Organic Carbon (mg/L)	251	0.0315	11.97	5.851	1.976
Particulate Carbon (mg/L)	251	0.0005	8.3800	1.9414	1.0847
Total Organic Carbon (mg/L)	251	0.032	18.330	7.792	3.351

Table 9. Mean, minimum, maximum, n, and standard deviation for water quality parameters over all stations sampled in 1998 and 1999 combined.

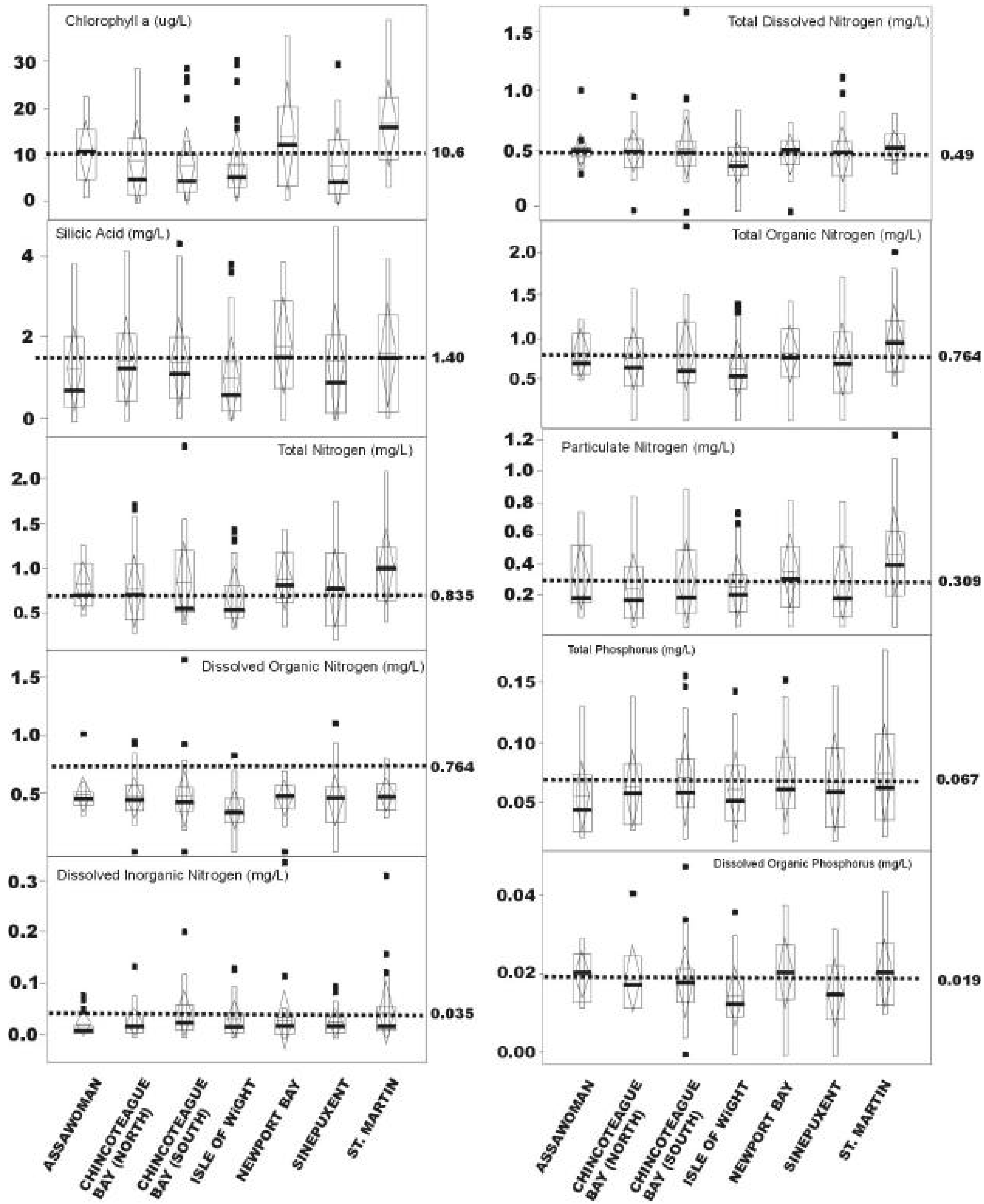

Figure 13. Box and whisker plots for water quality parameters.

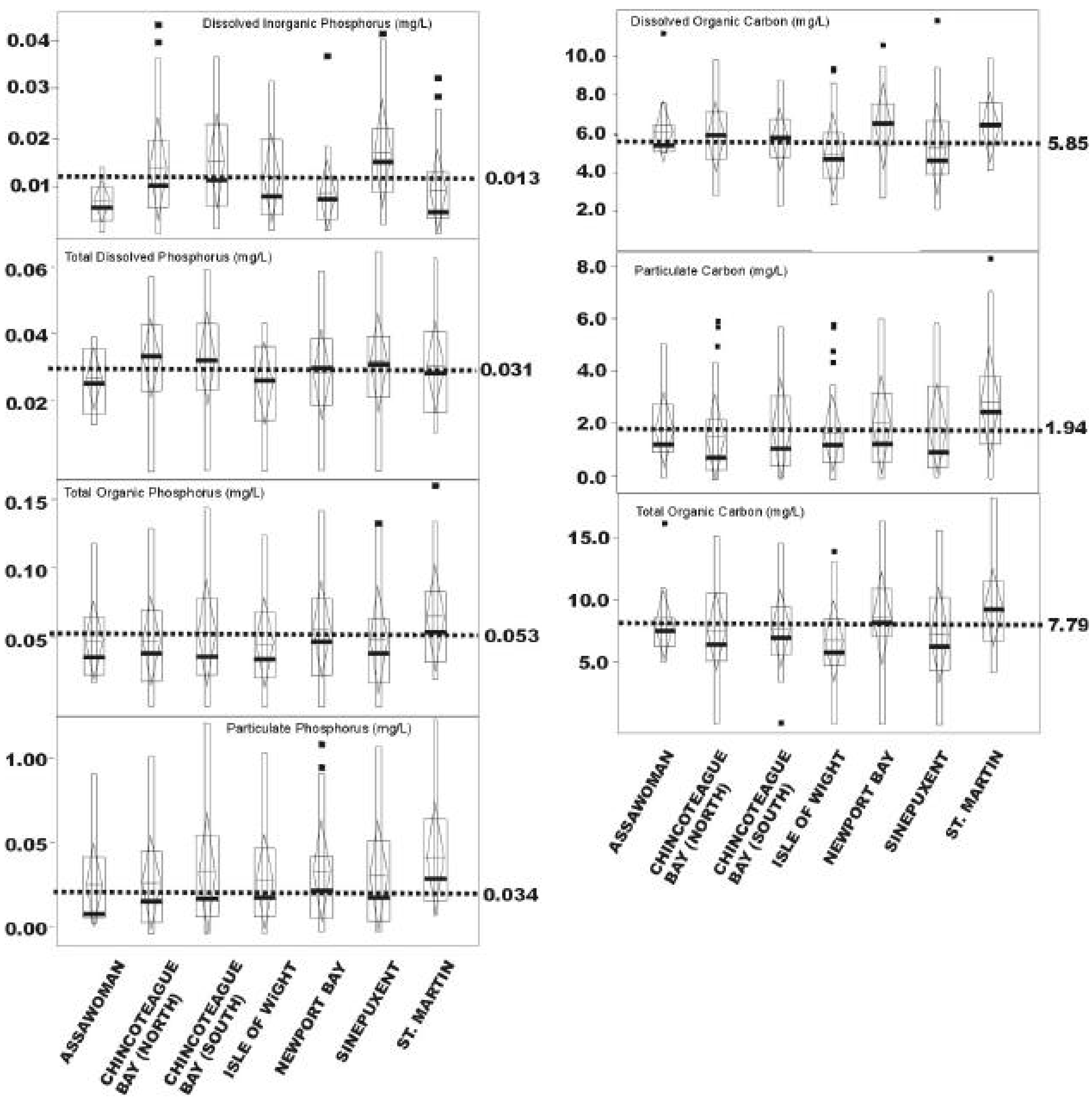

Figure 14. Box and whisker plots for water quality parameters.

AW	SM	NP	SN	IW	CH
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Chlorophyll *a* (ug/L)
p= <0.0001, F= 5.66
St. Martin significantly different from Sinepuxent, Isle of Wight and Chincoteague

AW	SM	NP	SN	IW	CH
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Silicic Acid (mg/L)
p=0.1520, F=1.64
No significant differences among embayments

AW	SM	NP	SN	IW	CH
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Total Nitrogen (mg/L)
p=0.0161, F=2.90
St. Martin significantly different from Isle of Wight and Chincoteague

AW	SM	NP	SN	IW	CH
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Dissolved Organic Nitrogen (mg/L)
p=0.0742, F=2.06
No significant differences among embayments

AW	SM	NP	SN	IW	CH
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Dissolved Inorganic Nitrogen (mg/L)
p=0.7398, F=0.55
No significant differences among embayments

AW	SM	NP	SN	IW	CH
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Total Dissolved Nitrogen (mg/L)
p= 0.0425, F=2.36
Isle of Wight significantly different from St. Martin

Figure 15a. ANOVA results for Chlorophyll a, Silicic acid, Total Nitrogen, Dissolved Organic Nitrogen and Total Dissolved Nitrogen.

AW	SM	NP	SN	IW	CH

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Total Organic Nitrogen (mg/L)
p=0.0207, F=2.76
St. Martin significantly different from Chincoteague and Isle of Wight

AW	SM	NP	SN	IW	CH

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Particulate Nitrogen (mg/L)
p = 0.0068, F=3.35
St. Martin significantly different from Chincoteague and Isle of Wight

AW	SM	NP	SN	IW	CH

Total Phosphorus (mg/L)
p=0.4513, f=0.95
No significant differences among embayments

AW	SM	NP	SN	IW	CH

Dissolved Organic Phosphorus (mg/L)
p= 0.0136, F=2.98
No significant differences among embayments

AW	SM	NP	SN	IW	CH

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Dissolved Inorganic Phosphorus (mg/L)
p=<0.0001, F=5.79
Sinepuxent significantly different from all embayments except Chincoteague; Chincoteague significantly different from Assawoman and Newport

Figure 15b. ANOVA results for Total Organic Nitrogen, Particulate Nitrogen, Dissolved Organic Nitrogen and Dissolved Inorganic Phosphorus.

AW	SM	NP	SN	IW	CH
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Total Dissolved Phosphorus (mg/L)
p = 0.0368, F=2.44
Isle of Wight significantly different from Chincoteague

AW	SM	NP	SN	IW	CH
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Total Organic Phosphorus (mg/L)
p = 0.2298, F= 1.39
No significant differences among embayments

AW	SM	NP	SN	IW	CH
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Particulate Phosphorus (mg/L)
p = 0.2979, F=1.23
No significant differences among embayments

AW	SM	NP	SN	IW	CH
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Dissolved Organic Carbon (mg/L)
p = 0.0225, F = 2.71
Newport significantly different from Sinepuxent and Isle of Wight

AW	SM	NP	SN	IW	CH
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Particulate Carbon (mg/L)
p=0.0082, F=3.25
Chincoteague significantly different from St. Martin

AW	SM	NP	SN	IW	CH
--------	--------	--------	--------	--------	--------

Total Organic Carbon (mg/)
p = 0.0171, F=2.86
No significant differences among embayments

Figure 15c. ANOVA results for Total Dissolved Phosphorus, Total Organic Phosphorus, Particulate Phosphorus, Dissolved Organic Carbon, Particulate Carbon and Total Organic Carbon.

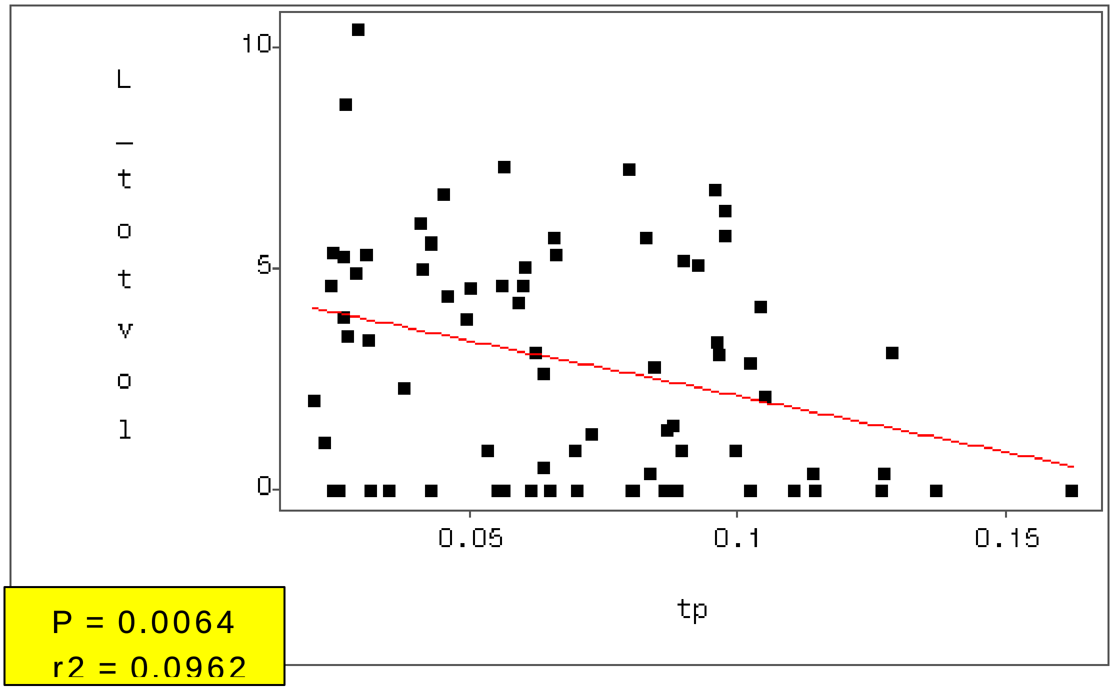

Figure 16. Total phosphorus (mg/L)vs. the log of the total volume of macroalgae.

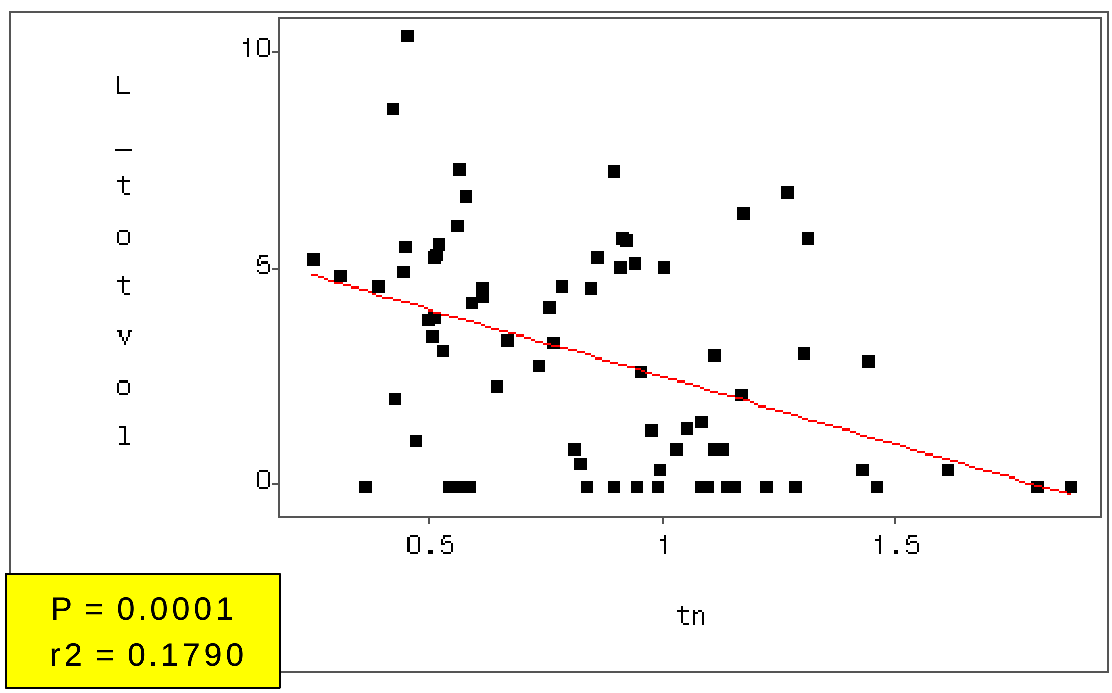

Figure 17. Total nitrogen (mg/L) vs. the log of the total volume of macroalgae.

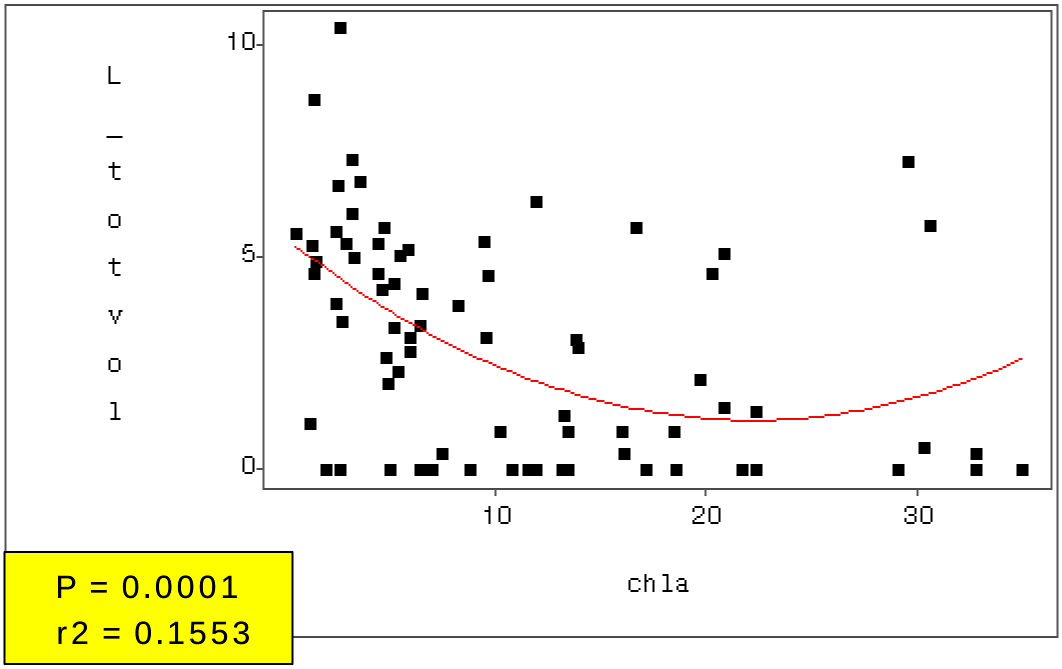

Figure 18. Chlorophyll a (ug/L) vs. log of the total macroalage volume.

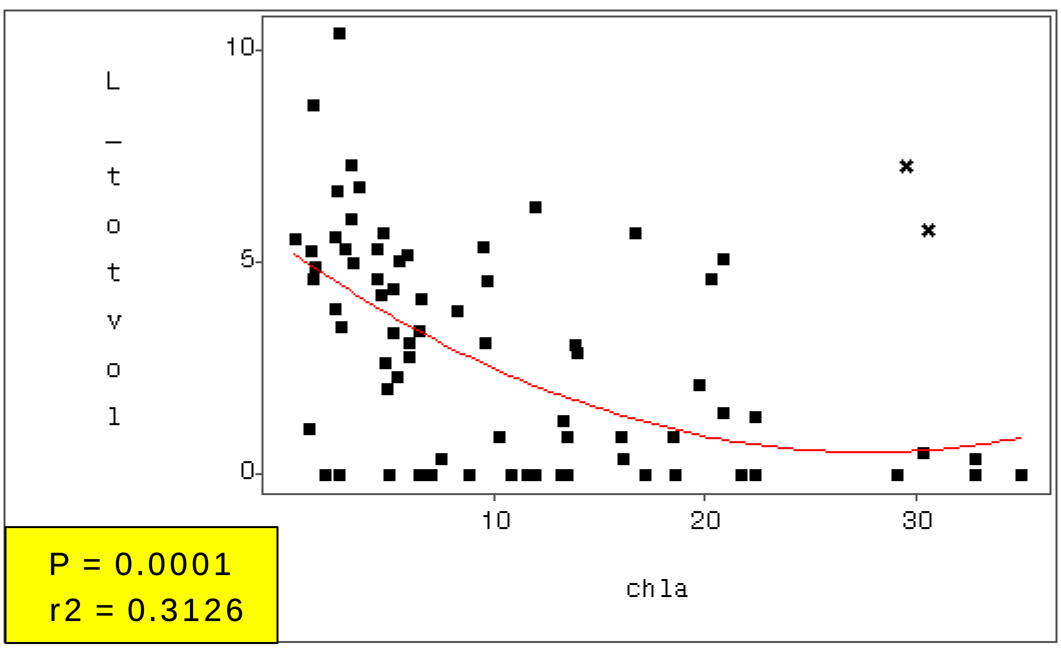

Figure 19. Total chlorophyll a (ug/L) vs. the log of the total macroalgae (two outliers

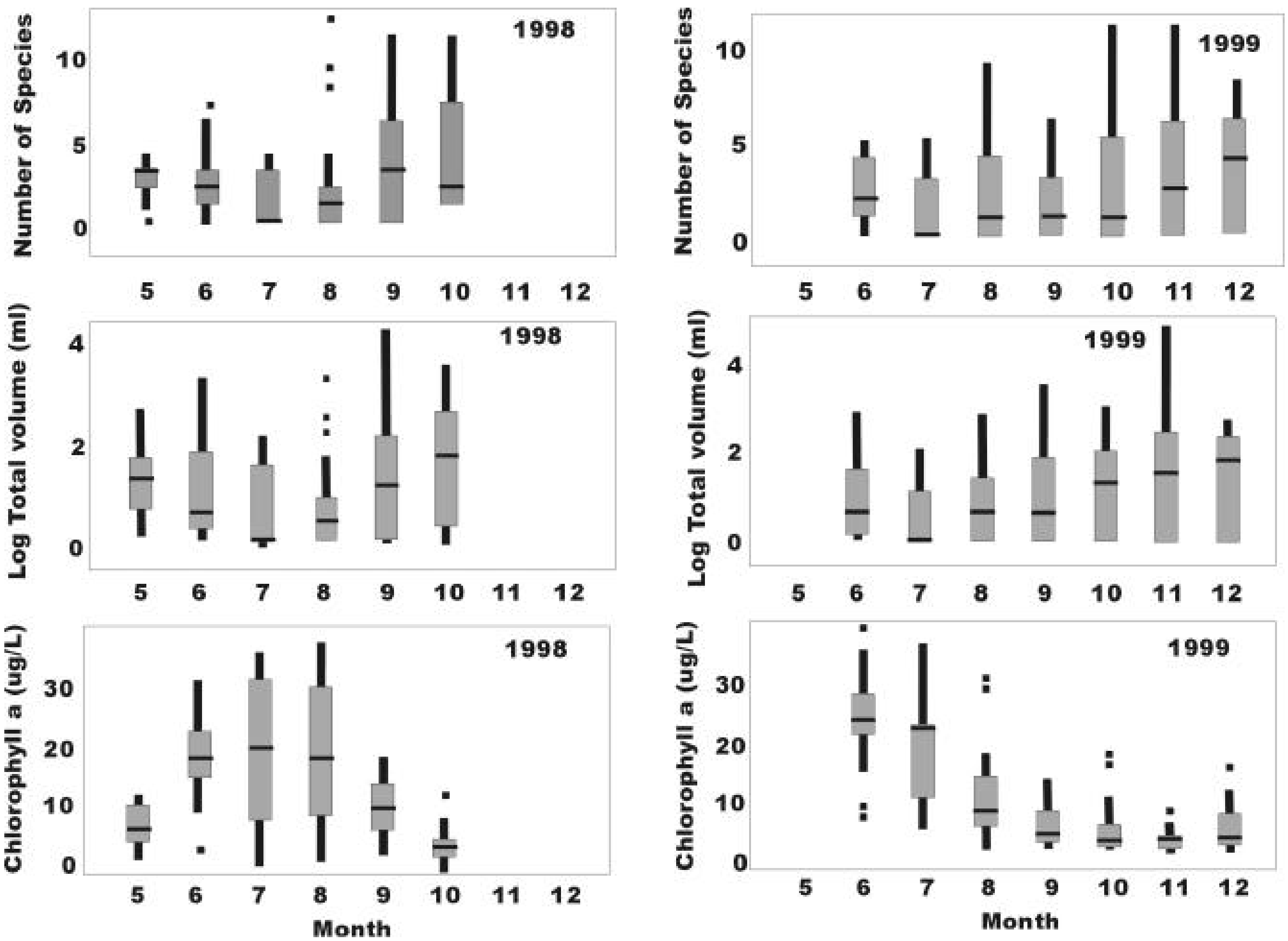

Figure 20. Distributions of genera, total volume and chlorophyll a by month for 1998 and 1999.

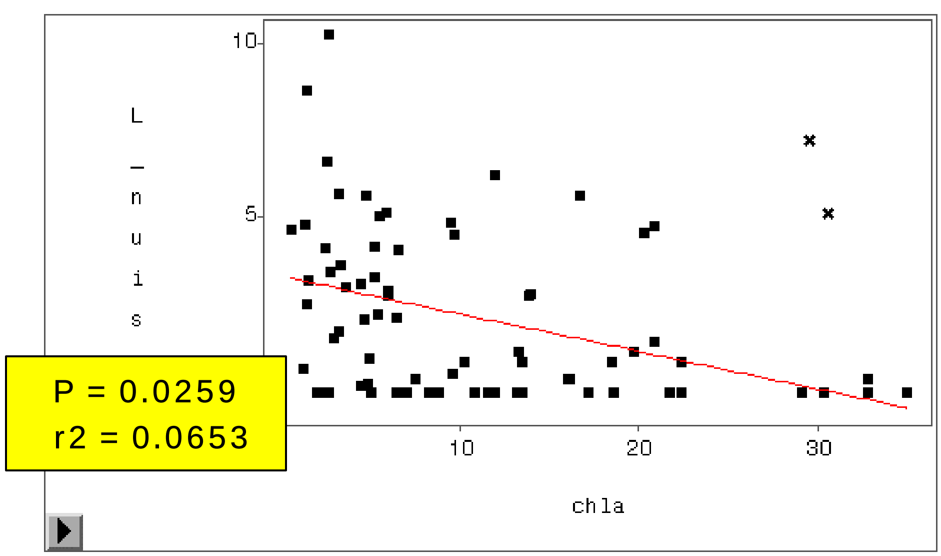

Figure 21. Log of nuisance algae genera volume vs. chlorophyll a.

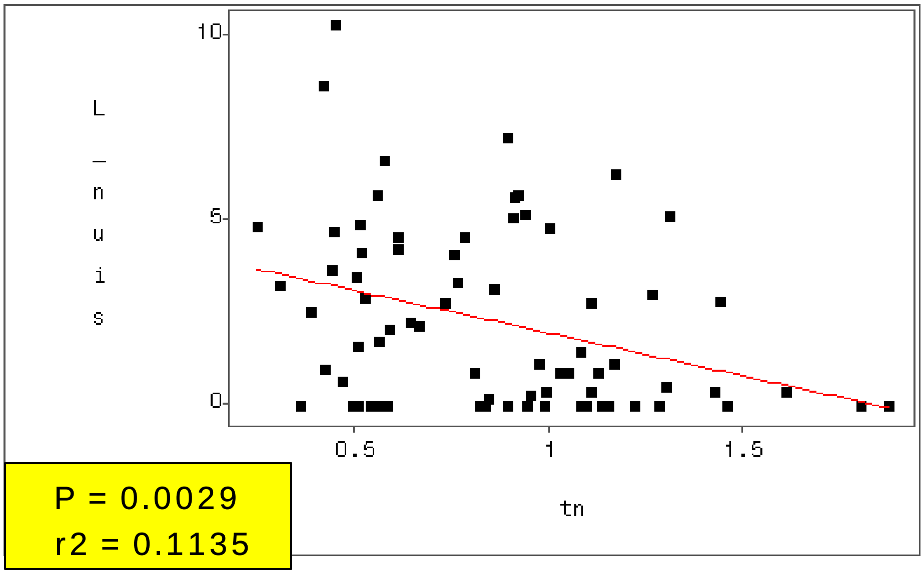

Figure 22. Log of nuisance algae genera volume vs. total nitrogen.

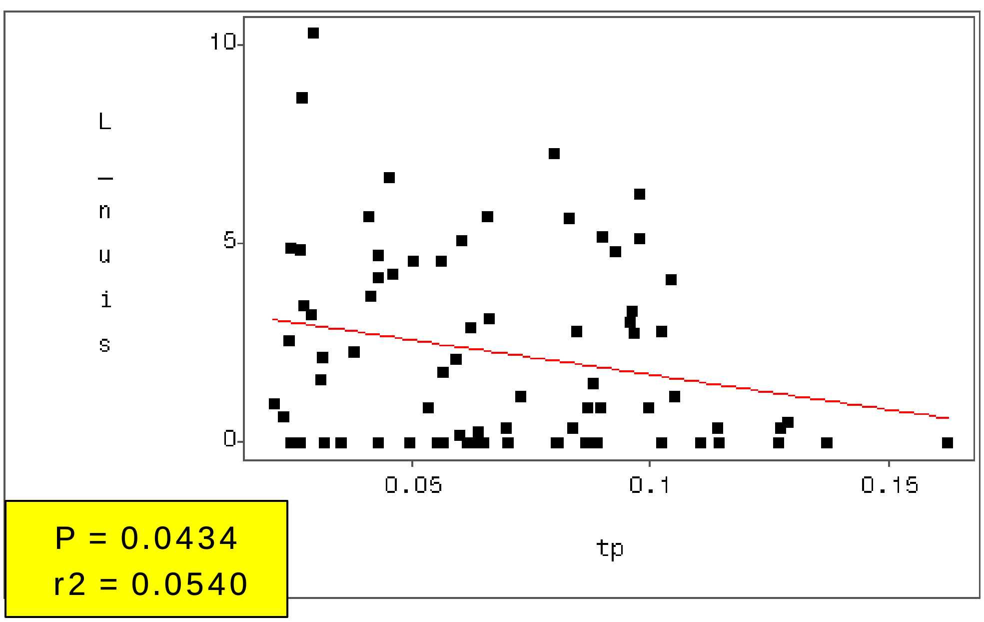

Figure 23. Log of nuisance algae genera volume vs. total phosphorua.

DISCUSSION

Twenty-five genera were documented in the Maryland Coastal Bays based on the observations of this study. This represents four more genera than those documented in 1996 in the Delaware inland bays (Timmons and Price, 1996). Of these genera observed, seven were dominant. These dominants are found throughout the bays, fairly widespread, and do not show an obvious gradient of decline from the northern to the southern bays. Additionally, the genera richness was greatest in Southern Chincoteague Bay local to the Maryland/Virginia state boundary. In terms of macroalgae volume, Isle of Wight Bay showed the greatest total volume of macroalgae and the greatest volume per station. Chincoteague Bay showed the second greatest abundance each year with Sinepuxent Bay ranking third. Prior to this study, it was assumed that there was a gradient of eutrophication, with high enrichment in the northern bays ranging to little enrichment in the southern bays. It was also assumed that Chincoteague bay was pristine and dominated by SAV, with little macroalgae present. However, results have shown that this assumption is incorrect and that southern Chincoteague Bay showed some of the largest volumes of macroalgae.

Two genera of macroalgae, *Chaetomorpha spp.* and *Cladophora spp.* have been reported as nuisance species, and are considered responsive to nitrate enrichment. Though these species were not observed in large abundance in this study, they have been observed in other settings in much larger abundance. *Chaetomorpha spp.* has been reported in extremely large abundance in SAV beds, and is a presumed threat to the health of the SAV beds (MD DNR, 1999). In fact, two of the areas cited in this study, with the largest *Chaetomorpha spp.* volume were local to areas that reportedly suffered declines in SAV in the year 2000 (Tingle's Island and Cord's Marsh), (Wazniak, personal communication).

In addition to *Chaetomorpha spp.* and *Cladophora spp.*, several other genera observed tend to benefit from nitrate enrichment. These genera, *Enteromorpha spp., Ulva spp., Gracilaria spp.* and *Agardhiella spp.,* were well distributed throughout the bays, and ranked high for frequency of occurrence and total volume. When we evaluated the distribution of these genera by volume, we saw that there were large volumes of these genera in localized areas along the entire north-south gradient.

Water quality parameters were compared among embayments to discern whether a north to south gradient exisited. Our analyses showed much variation within each embayment, for the measurement parameters. When we compared the mean concentrations using ANOVA, some differences among the embayments were seen. Generally these results showed that St. Martin River is significantly different than the other bays for chlorophyll *a* and the major nitrogen constituents. This was expected, as the EMAP (1996) study confirmed previous assumptions that the "major tributaries are in poorer condition than the mainstem water bodies." Though there were differences among the embayments, the concentrations of nutrients and chlorophyll *a* were generally low. One possibility for these low concentrations is that the areas sampled were in the more open water areas that are subject to high fetch and thus are well-mixed, seemingly homogenous waters. Another possibility is that our sampling areas tended to be down stream in areas distantly removed from surface run off, and thus, any nutrients coming off the land are intercepted upstream and unavailable to the receiving waters. A third possibility is that because these shallow coastal embayments tend to be benthic dominated, benthic diatoms and macroalgae are assimilating nutrients. The last possibility is that surface run off may not be the prime delivery mechanism of nutrients to the receiving waters. Whatever the case, we observed fairly low nutrient and chlorophyll a concentrations baywide, and did not see any obvious gradients.

Relationships between water column nutrients, chlorophyll *a*, and benthic macroalage volume (both total volume and volume of nuisance algae) tended to be weak when they were significant. Total nitrogen and total phosphorus, when compared to macroalgae, did little to explain the variation in macroalgae volume. The correlation between chlorophyll *a* and macroalage was better, but still weak. One thing that could possibly confound these comparisons is that many of the genera macroalgae that we observed can become detached and drift, thus, their distribution can be influenced by wind and current. Therefore, it is possible to get a large concentration of drift macroalage in an area where nutrient and chlorophyll *a* concentrations are low. It is also possible for macroalgae to grow in abundance, in an area of nutrient enrichment, just to be blown out of that area during a storm, to an area of ambient nutrient concentration. It is equally possible that these benthic macroalgae are not dependant on surface water nutrient sources, but groundwater or sediment nutrient sources instead. Valiela et al. (1997) found that macroalgae are efficient at intercepting regenerated nutrients from the sediments and that they "take up so much N that water quality seems high *(or good)* even where N loads are high." This may be why we observed the highest genera richness near the Maryland/Virginia line. The U.S. Geological Survey in a preliminary groundwater study, has recently found that groundwater nitrogen concentrations in that vicinity are elevated beyond natural concentrations and could possibly be enhancing the local macroalage community (Wazniak, personal communication).

Our initial survey and analyses does not allow us to support or reject the hypotheses. There was not a definitive nutrient gradient observed and thus, we can not define how the primary producer community would respond. We did observe a weak correlation between chlorophyll *a* and macroalgae volume, that suggests that chlorophyll *a* might replace macroalage under elevated nutrient conditions. In addition, we have seen small, localized losses of SAV in areas where *Chaetomorpha spp*. is abundant. Valiela et al. (1997) presented a model that showed a shift in the proportion of total net production from seagrass to macroalage to phytoplankton in response to nitrate loads. This model was developed from data taken from three small coastal embayments, similar to the Maryland coastal bays, and should be explored for local applicability. It is possible that we may be seeing early indications of nutrient enrichment bay-wide, however, we would need to further examine these relationships on a bay-wide scale before we draw any firm conclusions. Because the individual embayments tend to be so similar in their water quality characteristics, it would be more appropriate to evaluate the system as a single unit over time to test our initial hypothesis and apply the Valiela model.

Based on the information gained and the rising public concern over macroalgae, we will continue to evaluate the potential use of macroaglae as an indicator of nutrient enrichment. We will need to continue to monitor its distribution and abundance as well as nutrient loads to determine if indeed it is an adequate indicator of nutrient enrichment.

CONCLUSIONS

- We observed a diverse and well distributed macroalgae community in the Maryland coastal bays. (Twenty-five genera were observed.)
- The hypothesis, as stated, could not be evaluated because there was not an apparent nutrient gradient.
- The system should be evaluated as a single unit in order to model the dynamics of nutrients and

primary production, and apply the Valiela model (Valiela et al. 1997).

- We were able to gain much valuable information concerning the distribution of benthic macroalage in the coastal embayments. It has equipped us with needed information to enable us to respond to public inquiries and concern over 'nuisance macroaglae'.
- We will continue to explore the potential of macroalgae as an indicator of nutrient enrichment.

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